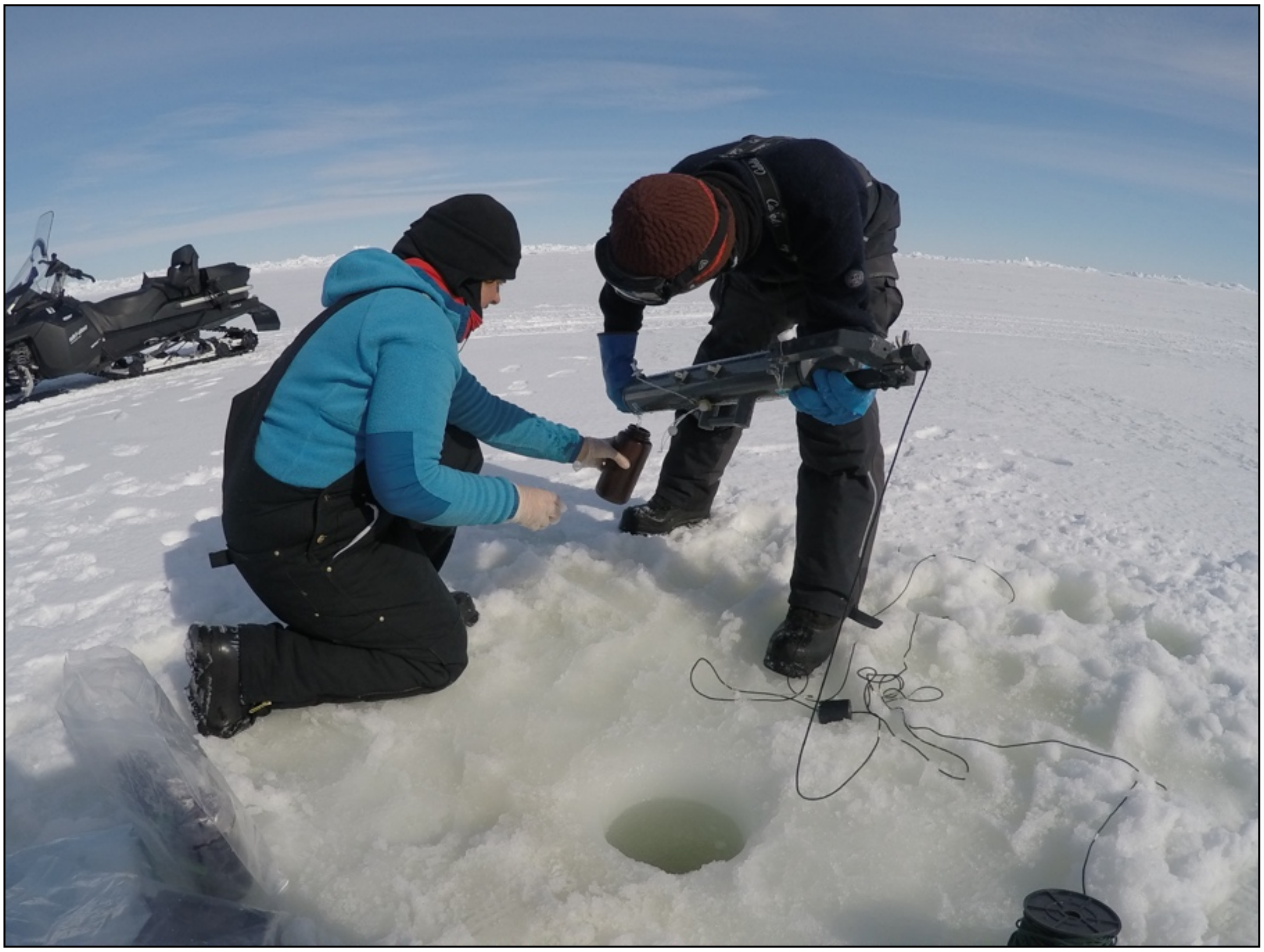
Nelson Estuary Landfast Ice Survey: Nanuk Lodge



Participants:

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Leg 1: Feb 19 – Mar 11, 2017

Leg 2: Mar 18 - Apr 5, 2017

Leg 3: Apr 5 – Apr 15, 2017

Introduction

BaySys is a comprehensive and interdisciplinary study that aims to contribute to a scientific basis to understand the relative contributions of climate change and regulation on the Hudson Bay system. The role of freshwater in Hudson Bay is being investigated through numerous field-based experimentation coupled with climatic-hydrological-oceanographic-biogeochemical modeling. Five teams led by an academic and industry co-lead have been organized to investigate a number of interconnected systems including: marine/climate systems, freshwater systems, marine ecosystems, carbon cycling, and contaminants. For the scientific and local Hudson Bay communities, this multidisciplinary project will vastly expand knowledge of climate impacts on the Arctic system, in a region where there are substantial gaps and limitations in existing knowledge. This field program was designed to collect data for 4 teams over 3 legs.

Study Area

This project took place on the landfast sea ice in southwestern Hudson Bay, near the mouth of the Nelson Estuary. The program was based out of the Nanuk Polar Bear Lodge, which is located near the shore of Hudson Bay between the mouth of the Nelson River and Cape Tatnam. The seasonal ice cover that forms annually within Hudson Bay is composed of both mobile pack ice and landfast ice that forms a narrow band of stationary ice in the near shore areas of Hudson Bay. In southwestern Hudson Bay the landfast ice provided an excellent opportunity to study the freshwater-marine coupling near the mouth of the Nelson River. The area is typically ice covered from November to June, though the landfast ice cover typically becomes unstable is forced offshore during May to early June.

Hudson Bay experiences large tides, for the Nelson Estuary the tidal range is ~4.5m. Hence, while the landfast ice is stationary it does move vertically and continue to behave dynamically. The large tidal range leads to grounding of some of the landfast ice, a concern for both collecting ice and water samples, but also deploying any sort of under ice autonomous equipment.

Logistical Summary

Overall there were 8 members of BaySys team 1 who took part in the Nanuk project:
David Babb – Leg 1 & 3 - Research associate with Dr. David Barber at CEOS. Studying
Dr. Igor Dmitrenko – Leg 1- Research scientist at CEOS, studying physical oceanography.

Dr. Sergei Kirillov – Leg 1 – Research associate with Dr. David Barber and Soren Rysgaard at CEOS, studying physical oceanography.
Dr. David Barber – Leg 2 – Canada Research Chair in Arctic-System Science, overall lead of BaySys.
Nathalie Theriault – Leg 2 & 3 - BaySys coordinator and research associate with Dr. David Barber at CEOS.
Vlad Petrusevich – Leg 2 & 3- PhD student with Dr. Igor Dmitrenko and Dr. Jens Ehn at CEOS, studying physical oceanography.
Atreya Basu – Leg 2 – PhD Student with Dr. Jens Ehn at CEOS, studying CDOM (Colored Dissolved Organic Matter) tracing in Hudson Bay.
Dr. Greg McCullough – Leg 2 – Research associate with Dr. David Barber at CEOS, studying freshwater in Hudson Bay and the Hudson Bay watershed.

Note that the scientific lead of Team 1, Dr. Jens Ehn did not come to Nanuk but was involved in all aspects of the science.

Team 1 – Sea and Oceanography

Objectives

Broadly, Team 1 had the objective of characterizing the physical properties of the landfast sea ice near the Nelson estuary and the underlying water column. Specifically we were interested in observing the freshwater-marine coupling processes that occur beneath the landfast ice cover. The Nelson River is the largest source of freshwater to Hudson Bay and while a majority of the ice cover in the Nelson estuary is mobile pack ice that is transported through the region, there is landfast ice that forms to the north, Nelson River to Cape Churchill, and to the east, Nelson River to Cape Tatnam.

The sampling plan for Team consisted of 3 transects across the landfast ice (shore to ice edge) and sporadic sampling along (Nelson to Cape Tatnam) the landfast ice cover, with both ice cores and water samples collected at each site. At the ice edge end of each transect there was an ice tethered mooring deployed for continuous monitoring of the water column, while an autonomous ice mass balance buoy was additionally deployed at one of the moorings to monitor the thermodynamic forcing of the ice cover. Below is a brief summary of the samples that collected by Team 1.

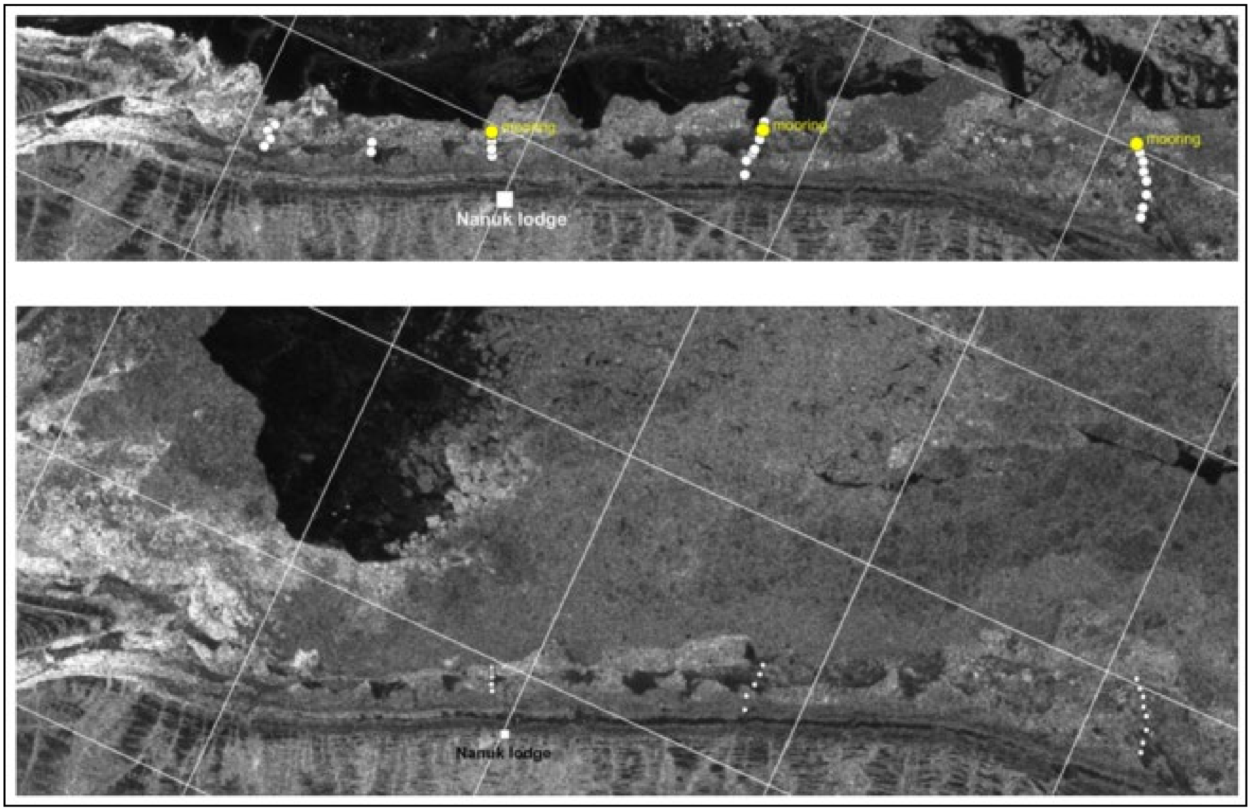


Figure 1 Sentinel SAR imagery along the coast in the area of research. The upper image show the landfast ice configuration on February 12. The lower image represents post-storm configuration of landfast ice as recorded on March 14. The white circles correspond to CTD stations carried out during leg 1

Sea ice

Sea ice physical properties: To assess the physical properties of the landfast sea ice cover, a series of ice cores were collected. Ice cores were collected with a Kovacs Mark II Core Barrel (9.25 cm in diameter). For each ice core the vertical temperature profile was sampled at 10cm intervals directly after the ice core was extracted from the core barrel. Subsequently the cores were sectioned at 10cm intervals, bagged, melted and sampled for salinity. An example of the salinity profiles from 4 locations along the landfast ice cover are presented below.

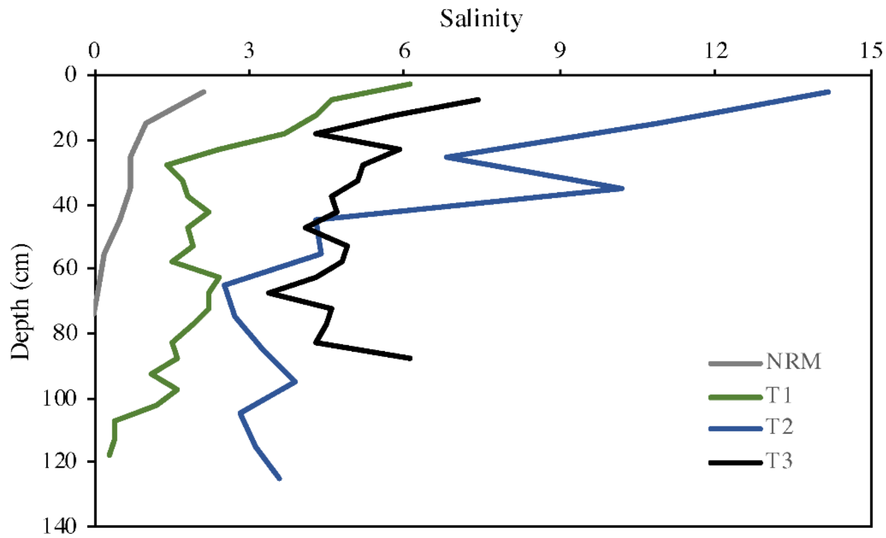


Figure 2 Sea ice salinity profiles from 4 locations on the landfast ice cover collected during Leg 3. NRM is the Nelson River Mouth. Samples were sectioned at 10 cm intervals

Sea ice thermodynamic growth: To monitor the thermodynamic growth of sea ice during our field study, an autonomous ice mass balance buoy (IMB) was deployed at one of the mooring sites. The IMB used a Campbell Scientific data logger to run an air temperature probe, barometer, snow depth sounder (189cm above ice surface) and a temperature string with sensors at 20 cm intervals from 40cm above the ice to 60cm depth, and then 10 cm intervals to the 320 cm depth. Data was collected at 30-minute intervals from February 23rd to April 12th. The snow sounder was deployed 189 cm above the ice surface. The air temperature probe and barometer were 155 and 157 cm above the ice surface, respectively.

Table 1 IMB Details

IMB Deployment:		IMB Recovery:	
Snow	10 cm	Snow	14 cm (SR50 – 175 cm)
Ice thickness	1.01 m	Ice thickness	
Notes:	T String depths (cm): 40, 20, 0(ice:snow interface), -20, -40, -60, -70, -80 and on at 10 cm intervals to the end of the T string.	Notes:	Bottom of the T string was damaged due to grounding. T sensors at 0, -20 and -40 cm depth did not work during the experiment.

	Deployed in a level area of ice surrounded by large ridges and within ~100m of the landfast ice edge		

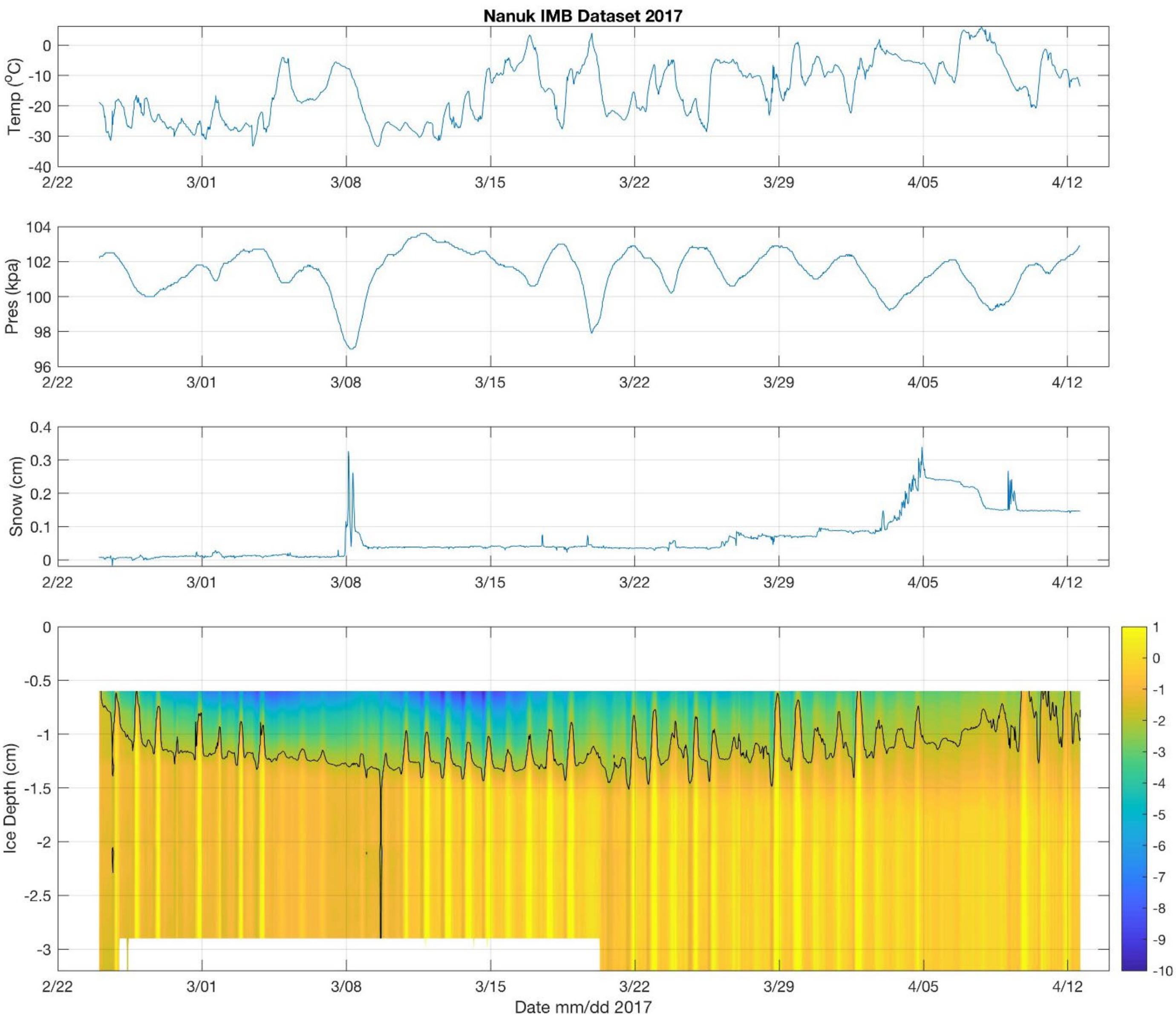


Figure 3 A sample of the data collected from the IMB at Mooring site 1 (near Nanuk Lodge). Air temperature (top panel), Air Pressure (second panel), Snow depth (third panel), vertical temperature profile (bottom panel).

Thickness: To characterize the ice thickness in the study area an electromagnetic induction system was brought to Nanuk with the intention of towing it behind a snow mobile and collecting a continuous record of ice thickness. However, there were technical issues with the instrument and due to very rough ice conditions the instrument was not used.

Surface Roughness – Drone Surveys: To characterize the roughness of the landfast ice cover a DJI-Phantom-4 Drone was used to conduct aerial surveys of subsections of the study area. The drone collected visible imagery and subsequently used the Pix4D software that uses photogrammetric overlap to derive a digital elevation models of the ice cover. The accuracy of the DEM is estimated to be 3x the pixel size (~2 cm). In total there were 27 surveys flown over the landfast ice near Nanuk. A table of the flight details is provide below, along with a map of the survey locations and an example of the DEM over an ice ridge.

Table 2 List of drone surveys conducted near Nanuk

Survey #	Date	X Coord	Y Coor	Notes
Survey 1	18-Mar	-91.66955943	57.12445518	
Survey 2	18-Mar	-91.67320923	57.12984728	
Survey 3	19-Mar	-91.67023956	57.12288419	
Survey 4	22-Mar	-92.48860972	57.05510674	
Survey 5	22-Mar	-92.48655937	57.05489372	
Survey 6	24-Mar	-91.71239372	57.16071564	
Survey 7	25-Mar	-91.71264315	57.16020565	

Survey 8	24-Mar	-91.71263653	57.16006889	Choppy DEM elevations, poor correction
Survey 9	25-Mar	-91.40073386	57.23999661	
Survey 10	25-Mar	-91.4021265	57.24039237	
Survey 11	25-Mar	-91.40522652	57.24903915	
Survey 12	25-Mar	-91.40483594	57.24662574	Many linear artefacts from correction
Survey 13	28-Mar	-90.9623231	57.33813783	
Survey 14	28-Mar	-90.95979698	57.33891903	
Survey 15	28-Mar	-90.96020263	57.33747226	
Survey 16	28-Mar	-90.97288718	57.33389766	
Survey 17	28-Mar	-90.97355595	57.33348371	
Survey 18	28-Mar	-90.97319522	57.33340299	
Survey 19	28-Mar	-91.67024242	57.1207665	
Survey 20	07-Apr	-91.96606171	57.10263883	

Survey 21	07-Apr	-91.9658484	57.10263337	
Survey 22	07-Apr	-91.8459039	57.12051569	
Survey 23	07-Apr	-91.83785999	57.10764032	
Survey 24	13-Apr	-91.71293308	57.16037872	
Survey 25	13-Apr	-91.7122521	57.16035942	
Survey 26	13-Apr	-91.70198954	57.14708244	
Survey 27	13-Apr	-91.70069303	57.14709552	

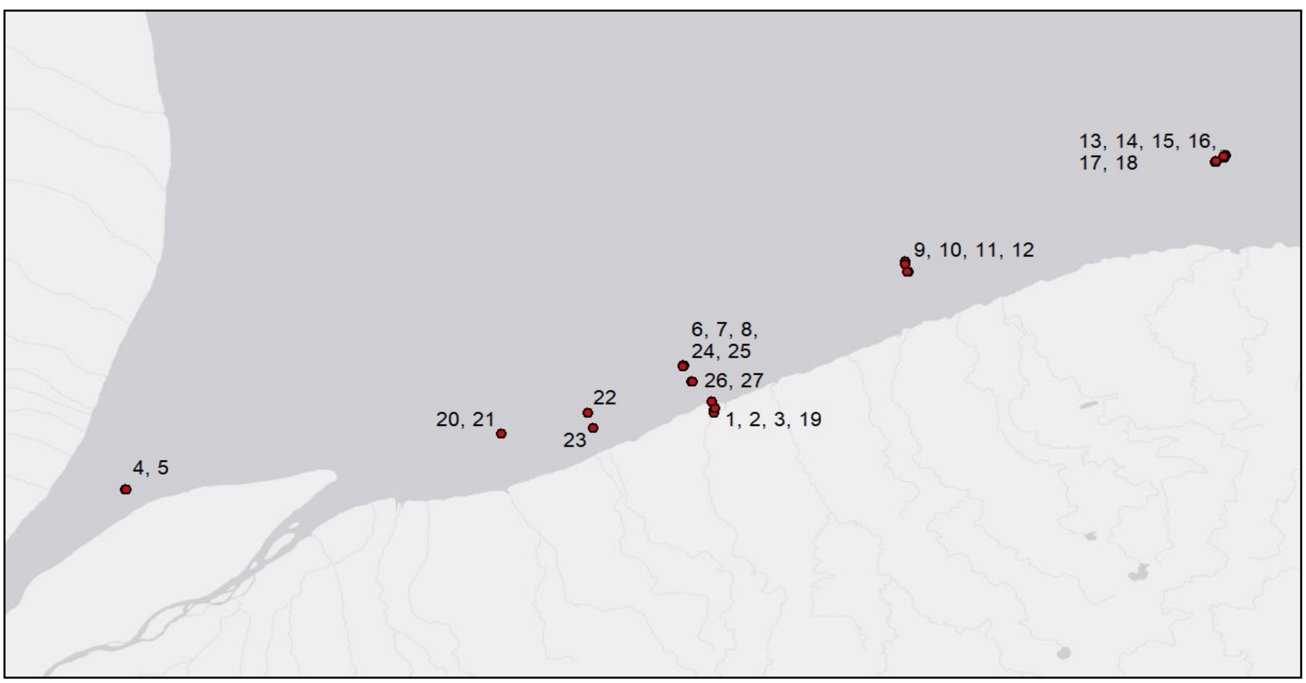


Figure 4 Map of the Drone survey locations

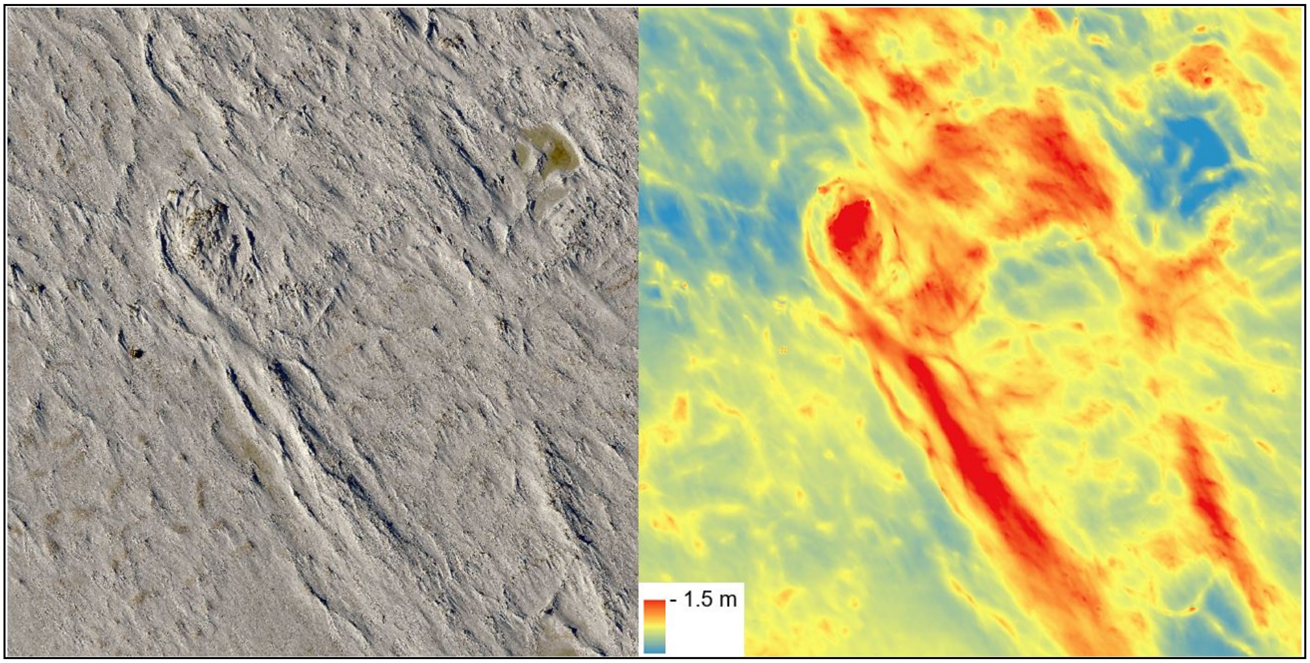


Figure 5 A sample photo mosaic and DEM derived from survey #27 over a ridge in the landfast ice cover near Nanuk

Oceanography: (Sergei, Igor and Vlad)

To monitor the thermohaline changes and water dynamics under the landfast sea ice along the Nanum coast three moorings were deployed at landfast edge, which corresponded to the marine termination of 3 basic CTD transects (see Fig. 4). All moorings were equipped with 3-4 CT (Tu) sensors deployed at different depths, bottom-mounted pressure sensors, and downward looking 600 kHz Nortek ADCP. All instruments were programmed to record data every 10 minutes but, due to unknown reason, several CT sensors did not record any reliable data. The current velocities were also recorded every 10 min with 50 cm vertical resolution. The overall length of records changed from 48 days at the mooring m01 to 40 days at m02, and it was 32 days only at m03. It should be noted also that relatively high tidal amplitude and shallow water led to situation when some instruments had periodically been touching sea floor.

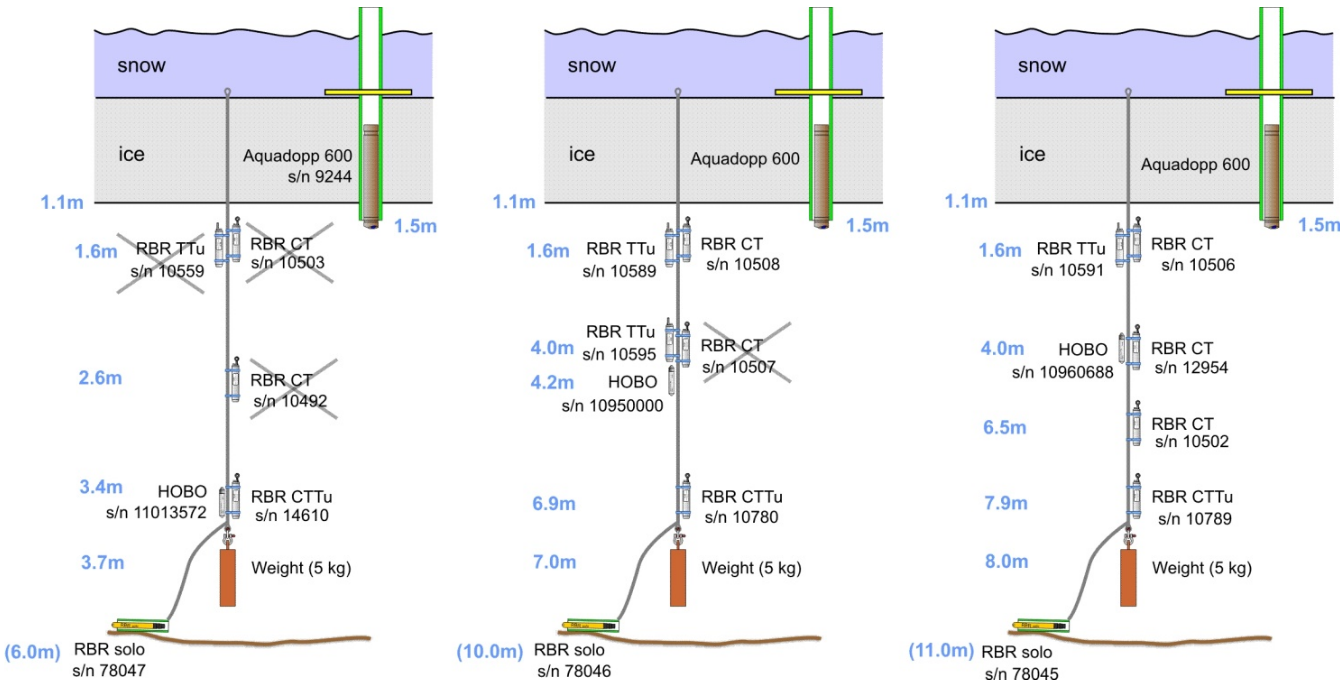


Figure 6 The schemes of m01, m02 and m03 moorings. Instruments with unreliable records are shown crossed

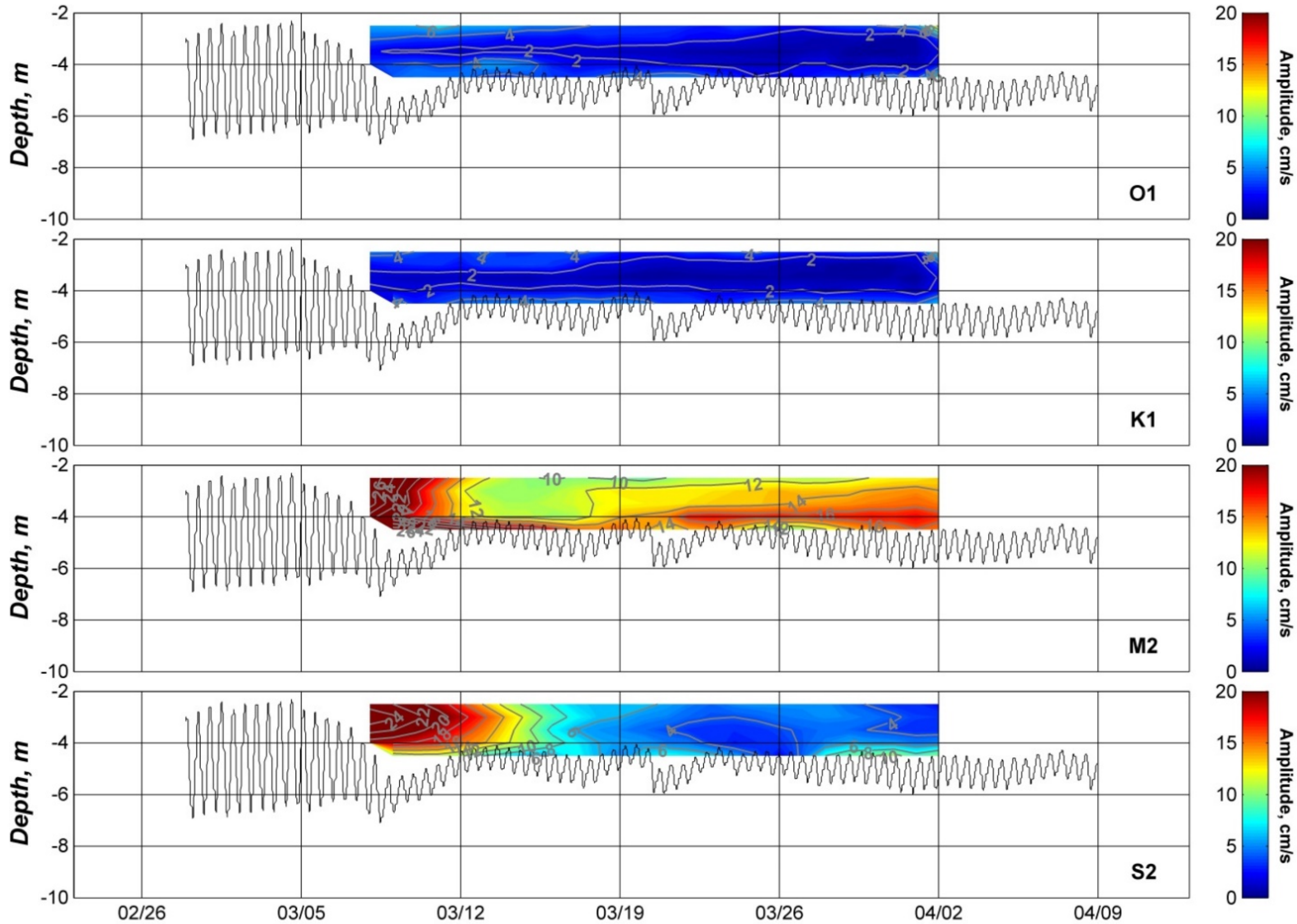


Figure 7 Temporal evolution of the most energetic constituents of tidal currents as measured in m02 position

Mooring records allowed to determine the impact of landfast ice on water dynamics under the ice cover. Specifically, it was found that the storm-induced increase of landfast ice extent from 4-6 km to 15-20 m led to considerable damping of tidal energy penetrating under the ice. The lunar semidiurnal amplitudes at moorings m01 and m02 decreased from 1.5-2.0 to 0.5-0.6 m with corresponding reduction of current velocities by factor near 2 (Fig. 7).

CTD Surveys

More than 120 oceanographic stations were made to specify the local thermohaline structure at different temporal and spatial scales. Temperature and salinity were measured with SeaBird 19plus profiler equipped with Chl-a fluorescence, turbidity and dissolved oxygen external sensors. Additionally, an Idronaut CTD was used to supplement the spatial sampling. Strong dynamics associated with tides over the shallow water, which depth does not exceed 8 m, and highly ridged landfast cover and edge make the area of research very difficult in terms of data interpretation. Some pronounced patterns can be distinguished though. First, all mentioned factors resulted absence of any vertical stratification: water column is well-mixed down to the bottom. Secondly, freshwater content decreased from west to east matching the distance increase from the Nelson and Hayes River mouths. Another interesting aspect of freshwater distribution involved off-shore decreasing of salinity at the first two transects, whereas salinity increased off-coast at the easternmost transect near cape Tatnam. This implies that fresher river waters were drawn toward the coast at some point between second and third basic transects.

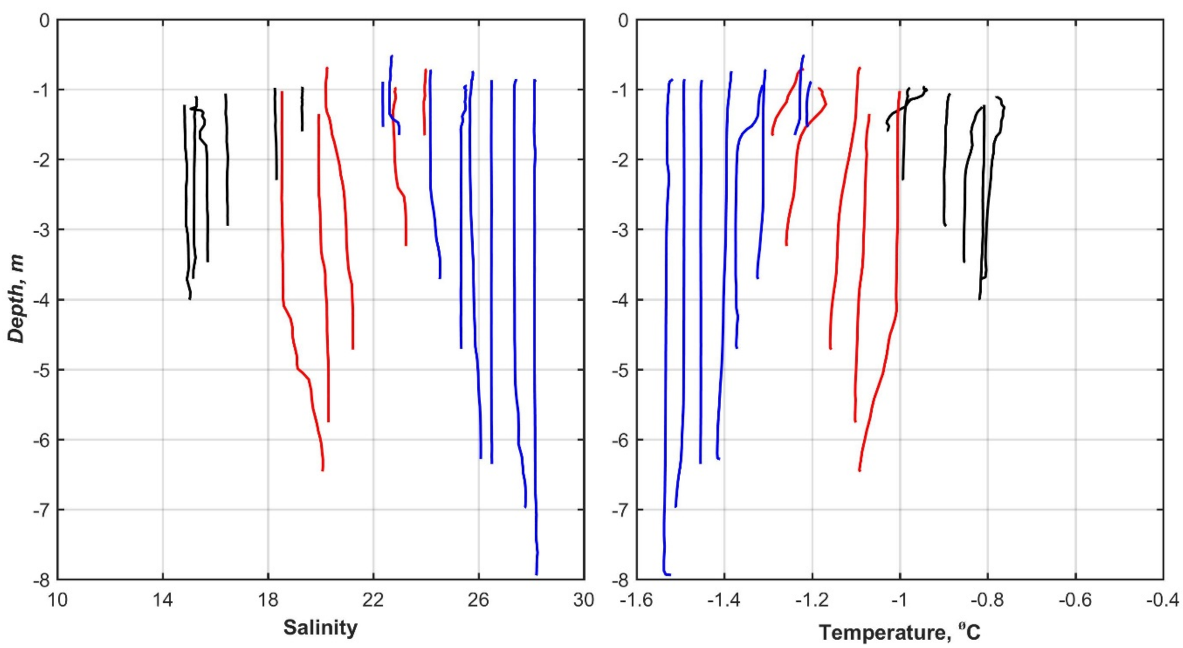


Figure 1 Salinity and temperature profiles recorded at 3 CTD transects across landfast ice. Black lines are associated with stations 1-6; red lines – stations 15-19; and blue lines – stations 7-14 (see Table 3)

Table 3 Coordinates of SeaBird CTD stations

Station NN	Latitude, N	Longitude, W	Depth, m	Date
1	57.1615	91.7139	4.05	2017 Feb 23 11:07:51
2	57.1601	91.7129	3.72	2017 Feb 23 11:31:47

3	57.1579	91.7106	3.48	2017 Feb 23 11:51:10
4	57.1556	91.7088	2.95	2017 Feb 23 12:07:08
5	57.1506	91.7049	2.31	2017 Feb 23 12:25:13
6	57.1467	91.7007	1.62	2017 Feb 23 12:59:13
7	57.3369	90.9617	7.94	2017 Feb 25 12:28:26
8	57.3320	90.9530	7.00	2017 Feb 25 12:52:31
9	57.3275	90.9448	6.35	2017 Feb 25 13:08:04
10	57.3213	90.9391	6.30	2017 Feb 25 13:23:06
11	57.3163	90.9312	4.73	2017 Feb 25 13:44:09
12	57.3076	90.9241	3.72	2017 Feb 25 13:59:15
13	57.2986	90.9214	1.70	2017 Feb 25 14:16:09
14	57.2919	90.9190	1.56	2017 Feb 25 14:33:50
15	57.2402	91.4022	6.53	2017 Feb 27 11:17:23
16	57.2336	91.4010	5.79	2017 Feb 27 12:07:08
17	57.2256	91.4017	4.73	2017 Feb 27 12:26:17
18	57.2163	91.4053	3.24	2017 Feb 27 13:11:14
19	57.2072	91.3998	1.67	2017 Feb 27 13:39:33
20	57.1601	91.7129	2.46	2017 Feb 28 16:44:58
21	57.1506	91.7049	1.44	2017 Feb 28 18:22:20
63	57.1496	91.7038	2.54	2017 Mar 21 10:39:15
64	57.1601	91.7129	3.87	2017 Mar 21 11:46:26
65	57.1506	91.7049	2.33	2017 Mar 21 13:49:50

67	57.1615	91.7139	4.19	2017 Mar 24 08:57:13
68	57.1506	91.7049	1.97	2017 Mar 24 15:18:28
69	57.1561	91.7093	2.71	2017 Mar 24 15:43:19
70	57.1579	91.7106	3.05	2017 Mar 24 16:11:29
71	57.1615	91.7139	3.33	2017 Mar 24 16:37:32
72	57.1601	91.7129	3.14	2017 Mar 24 16:59:35
73	57.2456	91.4049	5.86	2017 Mar 25 11:20:13
74	57.2402	91.4022	5.18	2017 Mar 25 11:46:22
75	57.2402	91.4022	5.16	2017 Mar 25 11:52:32
76	57.2336	91.4010	4.25	2017 Mar 25 12:32:04
77	57.2226	91.4017	3.25	2017 Mar 25 13:15:20
78	57.2163	91.4053	1.96	2017 Mar 25 14:06:46
79	57.3369	90.9617	5.29	2017 Mar 30 13:06:39
80	57.3163	90.9312	8.05	2017 Mar 30 14:53:00
81	57.1506	91.7049	3.17	2017 Mar 31 12:41:09
82	57.1561	91.7093	4.11	2017 Mar 31 13:17:55
83	57.1579	91.7106	4.63	2017 Mar 31 13:49:51
84	57.1601	91.7129	5.02	2017 Mar 31 14:23:12
85	57.1615	91.7139	4.96	2017 Mar 31 14:56:39
86	57.1467	91.7007	2.79	2017 Mar 31 16:11:42
87	57.1506	91.7049	3.36	2017 Mar 31 16:29:02
88	57.1561	91.7093	3.91	2017 Mar 31 16:43:23

89	57.1579	91.7106	4.21	2017 Mar 31 16:54:49
90	57.1601	91.7129	4.53	2017 Mar 31 17:06:31
91	57.1615	91.7139	4.54	2017 Mar 31 17:16:01
92	57.1467	91.7007	1.79	2017 Apr 02 08:51:36
93	57.1506	91.7049	2.31	2017 Apr 02 09:15:25
94	57.1561	91.7093	2.90	2017 Apr 02 09:37:57
96	57.1579	91.7106	3.19	2017 Apr 02 09:59:27
97	57.1601	91.7129	3.38	2017 Apr 02 10:17:41
98	57.1615	91.7139	3.43	2017 Apr 02 10:28:49
99	57.1601	91.7129	3.26	2017 Apr 02 11:03:36
100	57.2402	91.4022	4.85	2017 Apr 05 10:58:07
101	57.2456	91.4049	5.28	2017 Apr 05 12:40:35
102	57.2256	91.4017	2.68	2017 Apr 05 14:02:34
103	57.2163	91.4053	1.72	2017 Apr 05 15:06:24
105	57.1615	91.7139	3.23	2017 Apr 06 14:20:22
106	57.1602	91.7129	3.21	2017 Apr 06 14:31:10
107	57.1580	91.7109	2.98	2017 Apr 06 14:39:30
108	57.1556	91.7088	2.69	2017 Apr 06 14:50:05
109	57.1556	91.7088	2.03	2017 Apr 06 14:59:01
110	57.1506	91.7049	1.36	2017 Apr 06 15:07:46
111	57.1615	91.7139	3.17	2017 Apr 06 15:26:43
112	57.1602	91.7129	3.13	2017 Apr 06 15:38:12

113	57.1580	91.7109	2.88	2017 Apr 06 15:46:18
116	57.1556	91.7088	2.61	2017 Apr 06 15:55:55
117	57.1556	91.7088	1.97	2017 Apr 06 16:04:59
118	57.1506	91.7049	1.34	2017 Apr 06 16:14:55
119	57.1615	91.7139	3.32	2017 Apr 06 16:39:26
120	57.1602	91.7129	3.28	2017 Apr 06 16:48:27
121	57.1580	91.7109	3.02	2017 Apr 06 16:58:43
122	57.1556	91.7088	2.77	2017 Apr 06 17:08:23
123	57.1556	91.7088	2.14	2017 Apr 06 17:18:27
125	57.1506	91.7049	1.52	2017 Apr 06 17:29:32
126	57.1615	91.7139	3.53	2017 Apr 06 18:01:23
127	57.1602	91.7129	3.56	2017 Apr 06 18:11:33
130	57.1580	91.7109	3.29	2017 Apr 06 18:23:17
131	57.1556	91.7088	3.07	2017 Apr 06 18:32:09
132	57.1556	91.7088	2.45	2017 Apr 06 18:40:20
133	57.1506	91.7049	1.79	2017 Apr 06 18:47:56
134	57.1615	91.7139	3.83	2017 Apr 06 19:01:36
135	57.1602	91.7129	3.81	2017 Apr 06 19:08:55
136	57.1580	91.7109	3.55	2017 Apr 06 19:17:00
137	57.1556	91.7088	3.28	2017 Apr 06 19:23:37
138	57.1556	91.7088	2.68	2017 Apr 06 19:32:39
139	57.1506	91.7049	2.02	2017 Apr 06 19:40:28

140	57.1615	91.7139	4.04	2017 Apr 06 19:53:09
141	57.0977	91.9720	3.16	2017 Apr 07 09:49:59
143	57.1032	91.9666	3.60	2017 Apr 07 10:45:38
144	57.1032	91.9666	3.58	2017 Apr 07 12:03:42
145	57.0977	91.9720	3.14	2017 Apr 07 12:13:55
146	57.0932	91.9647	3.17	2017 Apr 07 12:32:28
147	57.0870	91.9673	2.42	2017 Apr 07 12:53:41
148	57.1204	91.8459	2.89	2017 Apr 07 14:44:16
149	57.1143	91.8418	2.05	2017 Apr 07 15:30:55
151	57.1615	91.7139	4.14	2017 Apr 11 11:01:52
152	57.1601	91.7129	4.25	2017 Apr 11 11:31:33
153	57.1601	91.7129	4.49	2017 Apr 11 11:57:42
154	57.1615	91.7139	4.40	2017 Apr 11 12:05:25
155	57.1601	91.7129	4.48	2017 Apr 11 13:01:56
156	57.1615	91.7139	4.39	2017 Apr 11 13:07:29
157	57.1601	91.7129	4.32	2017 Apr 11 14:03:21
158	57.1615	91.7139	4.26	2017 Apr 11 14:08:18
159	57.1601	91.7129	4.17	2017 Apr 11 15:01:51
160	57.1615	91.7139	4.06	2017 Apr 11 15:06:14
161	57.1601	91.7129	3.99	2017 Apr 11 15:59:25
162	57.1615	91.7139	3.87	2017 Apr 11 16:05:09
163	57.1601	91.7129	3.79	2017 Apr 11 17:00:18

165	57.1601	91.7129	3.71	2017 Apr 11 17:07:21
166	57.1615	91.7139	3.63	2017 Apr 11 18:00:31
167	57.1601	91.7129	3.53	2017 Apr 11 18:05:52
168	57.1615	91.7139	3.46	2017 Apr 11 19:01:31
169	57.1601	91.7129	3.45	2017 Apr 11 19:03:44
170	57.1615	91.7139	3.36	2017 Apr 11 19:08:17

Under Ice CDOM and Suspended Sediments

Colored Dissolved Organic Matter (CDOM) was used as a proxy to trace the under-ice freshwater plume. Along with CDOM, suspended sediments in the water column was measured to assess the sediment load capacity of the Nelson-Hayes River plume during the winter months. Both parameters were collected for the under-ice water at the mooring locations. A tidal period-based sampling approach for CDOM and suspended sediment was adopted for the Mooring: M01. This sampling approach involved a transect sampling where the first sampling point was close to the Nanuk Polar Bear Lodge and the last point was the mooring: M01. Aquascat, an acoustic device to monitor the sediment suspension process in the water column was moored near the mooring M01. It was deployed for a period of Leg 2 and 3. Discrete samples collected for suspended sediment analysis were also analyzed in the temporary laboratory of Nanuk Polar Bear Lodge for particle size distribution analysis using Microtrek particle size analyzer. Collected CDOM samples were brought back to CEOS for its absorption measurement using Perkin Elmer Lambda 650S UV-VIS spectrophotometer for a wavelength range of 250-800nm. Standard vacuum filtration technique was adopted for Total Suspended Solid (TSS) measurement. The filtered samples were brought to CEOS for oven drying at 104° and 500° followed by precision weighing after each drying step. The oven drying and weighing process was repeated for each sample until the error margin was below 0.0002 g/l.

Meteorological conditions: A meteorological station was deployed on land near the Nanuk lodge to collect a continuous record of surface meteorological conditions throughout the field program. Air temperature, winds, pressure and humidity were collected at 10-minute intervals at a height of ~ 5m above ground. The system collected a complete record during leg 1, but failed in between legs and collected data intermittently during legs 2 and 3. The issue was power supply to the station. A sample of the data is provided below.

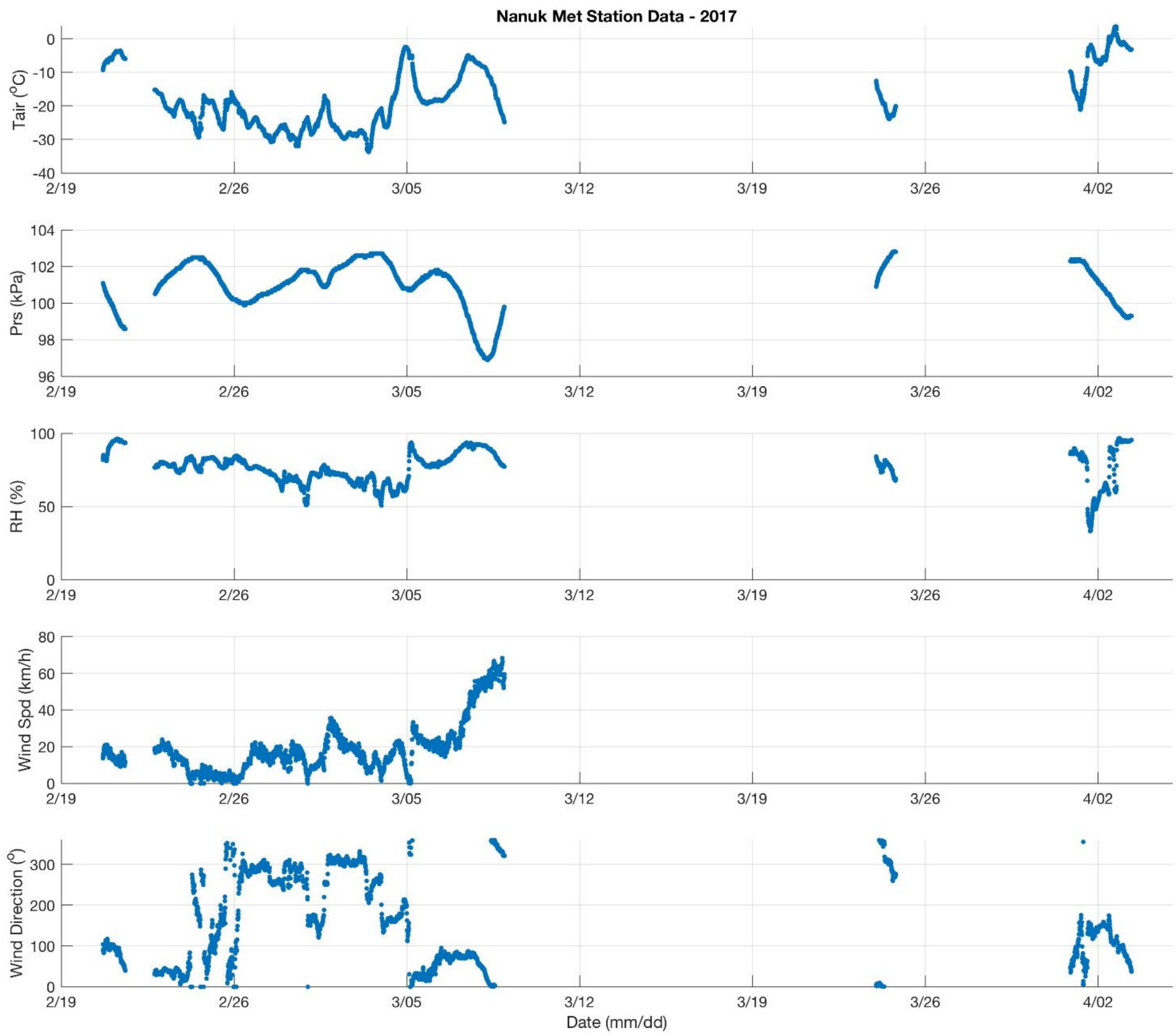


Figure 9 A sample of the Met data collected at Nanuk during the field program

Additional observations

The landfast ice cover was much rougher than anticipated. While the landfast is stationary it was clearly very dynamic during its initial formation and had continued to be dynamically deformed under tidal fluctuations. At several places there were very large ridges that formed parallel to the shore. It's likely that these ridges were grounded and were more pronounced during law tide when the free-floating ice surrounding them dropped with the tide.

The stamukhi at the landfast ice edge was very pronounced and was predominantly comprised of layers of thin ice that had been dynamically deformed into much larger pieces of ice. Due to the high tidal range the landfast ice edge was a very dynamic area, with the formation of large areas of open water on a diurnal cycle as a result of the tidal cycle. With cold atmospheric temperatures the exposure of open water along the landfast ice edge led to considerable new ice formation. However this ice was subsequently deformed as rising tides pushed the mobile ice cover back towards the landfast ice.

The extent of the landfast ice cover increased episodically during winter 2017 as mobile ice adhered to the landfast ice and extended its coverage. Below are 4 images from Sentinel that show the growth of the landfast ice from mid-January to mid-February.

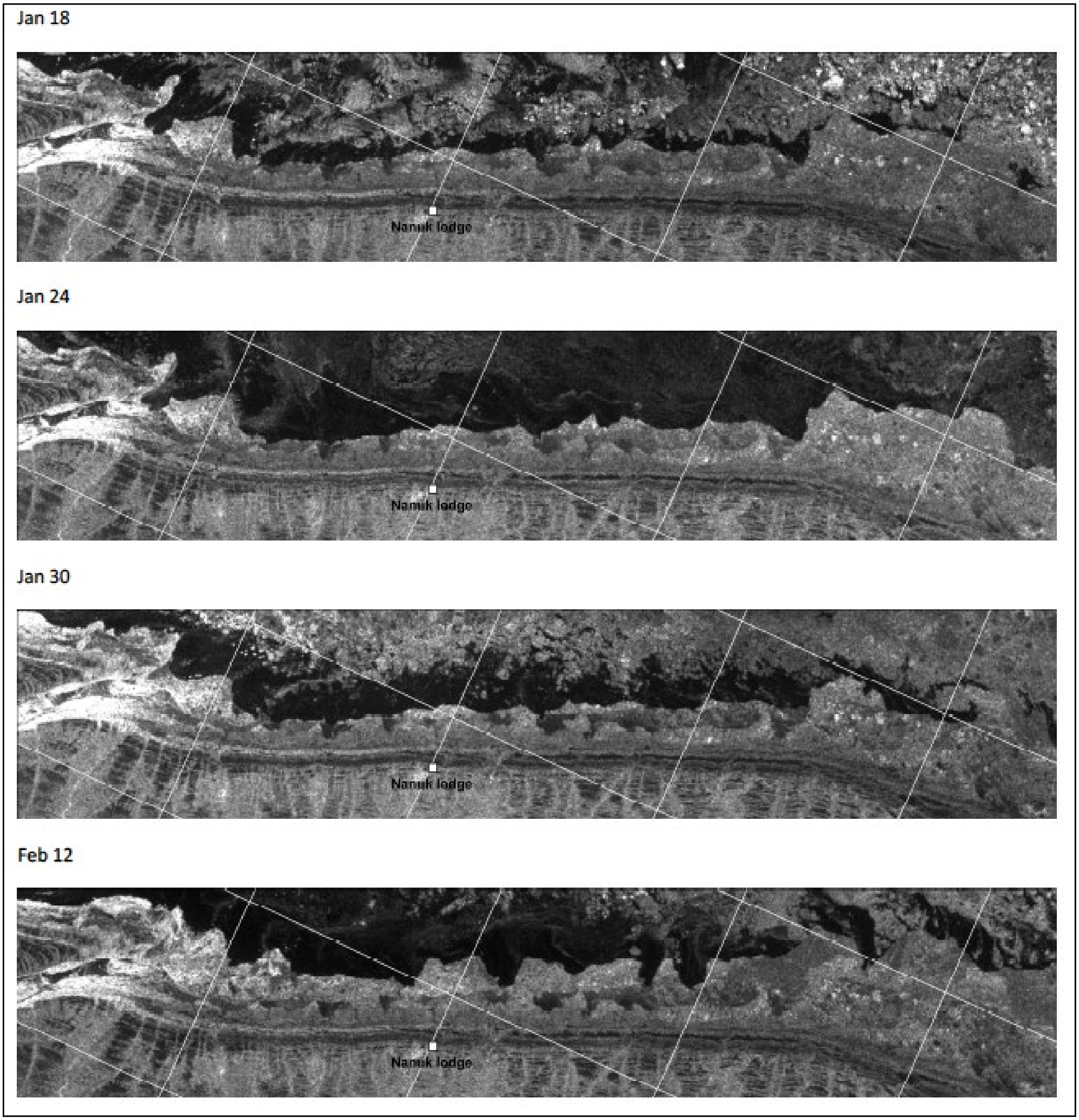


Figure 10 Sentinel-1 images over the landfast sea ice near Nanuk during 2017. The Nelson estuary is to the left and Cape Tatnam to the right. Black areas indicate open water, while the lower portion (south) of each image is land

Schedule of Sampling Activities

Leg 1:

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
2/19	2/20	2/21	2/22	2/23	2/24	2/25
Team arrived at Nanuk	Weather delay	Weather delay	Weather delay. 1st cargo flight	Survey D 1 CTD Transect IMB and Mooring #1 deployed	2nd cargo flight ID & SK went west for CTD transect Other team members setup labs and equipment	Survey D 2
2/26	2/27	2/28	3/01	3/02	3/03	3/04
						Scheduled departure
3/05	3/06	3/07	3/08	3/09	3/10	3/11
Weather delay	Weather delay	Weather delay	Weather delay	Weather delay	Weather delay	Departure to Thompson

Leg 2 & 3:

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
3/12	3/13	3/14	3/15	3/16	3/17	3/18
						Team arrived for Leg 2
3/19	3/20	3/21	3/22	3/23	3/24	3/25
	Weather delay					
3/26	3/27	3/28	3/29	3/30	3/31	4/01
			Partial crew change			

			Out: DBarber In: GM			
4/02	4/03	4/04	4/05	4/06	4/07	4/08
			Crew change from 2 -3 Out: GM, AB In: DBabb			
4/09	4/10	4/11	4/12	4/13	4/14	4/15
			IMB & Mooring #1 retrieved	Packing	Departure to Thompson	Team drove back to Winnipeg

Team 3 – Marine Ecosystems

The availability of light and nutrients controlled by physical oceanic processes and river runoff determine the timing and magnitude of biological productivity. In winter, light transmission through snow covered sea ice is very low while nutrient loading is influenced by different freshwater discharges of unregulated vs. regulated rivers. The aim of team 3 sampling was to examine the influence of the hydro-regulated Nelson River on the biological productivity under landfast sea ice during the winter-spring transition. Simultaneously, light propagation through the ice cover and primary productivity at the ice bottom and in the water column was measured.

Sea Ice sampling

Ice samples were collected using a 9 cm Mark II Kovacs core barrel. The bottom 5 cm and 5-10 cm of 3-5 cores were pooled together in their respective sections for each site and the bottom skeletal later (1-2 cm) of 3-5 cores were scraped into 500 mL of filtered seawater. A separate core was taken for analysis of bulk nutrients on the bottom 5 cm and a section from 5-10 cm. A full core was also taken to measure temperature and salinity for 0-5 cm sections for a full ice profile. These values will be used to calculate percent brine volume.

Figure 11 Pulling up the core barrel after taking a full ice core

The bottom 0-5 cm and 5-10 cm sectioned pooled cores were melted in the dark and 0.2 μm filtered seawater (FSW) was added at a ratio of three parts FSW to one-part ice. The melted pooled cores were then subsampled for the following variables that were filtered on Whatmann GF/F filters, frozen at -20°C and brought south for analyses: chlorophyll a, particulate organic carbon and nitrogen, high-performance liquid chromatography, particulate spectral absorption, algal taxonomy (via visible microscopy) and flow cytometry. The scraped cores were then subsampled for the following variables that were either fixed and/or frozen at -20°C for analyses: intracellular nutrients, chlorophyll a, and particulate organic carbon and nitrogen. Sample analysis is currently ongoing.

Under-ice light measurements

For ice algae available photosynthetic active radiation (PAR, 400 – 700 nm) was measured 10 cm below the ice bottom. A UV-visible hyperspectral radiometer (Cosine RAMSES-ACC, TriOS GmbH, Germany) was mounted to a metal arm and faced upward 1.50 m away from a drilled hole. To calculate light transmission incident radiation and albedo was measured with the same sensor at the ice surface. Ice thickness and snow depth was also recorded.

Water sampling

Interface water at the ice bottom close to the river estuary and marine water of several depth levels at the landfast sea ice sampling sites was collected to characterize the biological and chemical properties of the water column.

Samples for inorganic nutrients (ammonium, nitrite, nitrate, orthophosphate and orthosilicic acid) were taken from the water column after a filtration through pre-combusted GF/F filters inserted in a filter holder at all stations. Samples for nitrite, nitrate, orthophosphate and orthosilicic acid were collected into acid-washed 15ml polyethylene tubes and immediately frozen until further analysis at the Université Laval (Hansen and Koroleff 2007. Ammonium samples were incubated and measured using the fluorometric method of Holmes et al. (1999). Water samples for dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) were pre-filtered through pre-combusted GF/F filters to remove large particles and acidified with Hydro chloric acid. The samples were stored at 4 °C in fridge until further analysis. Samples for chlorophyll-a (chl-a) measurements were collected from the water column and filtered through GF/F filters. The pigments in filters were extracted in 90% acetone at 4 °C in the dark for 24h. The chl-a concentrations were measured using Tuner Designs 700 flourometer (before and after acidification).

In order to determine nitrate, ammonium uptake rates and primary production, 500 ml or 1000 ml of water samples from the surface were incubated during 24h at high (about 60 µE m2/s) and low (about 5 µE m2/s) light intensities to compare different light regime with 13C- 15N stable isotopic labeling technique. After incubation, water samples from incubations were filtered through a pre-combusted GF/F filters and filters were immediately frozen. Isotopic ratios of nitrogen and carbon from GF/F filters and water samples will further be analyzed using mass spectrometry. Filtrate samples from ammonium uptake were also kept and frozen to determine nitrification rates. Water samples for the natural abundance of 15N and 18O isotopes in nitrate were collected into acid-washed 50ml polyethylene tubes and immediately frozen.

Table 3 Water sampling parameters collected by BaySys team 3

Chl a	Chlorophyll a concentration
NO3, NO2, Si, PO4	Nitrite, nitrate, orthophosphate and orthosilicic acid

NH4	Ammonium
15N and 18O isotopes	Natural abundance of 15N and 18O isotopes in nitrate
15N and 13C uptake	Incubation with 15N and 13C tracers to determine nitrogen uptake rates and primary production estimates

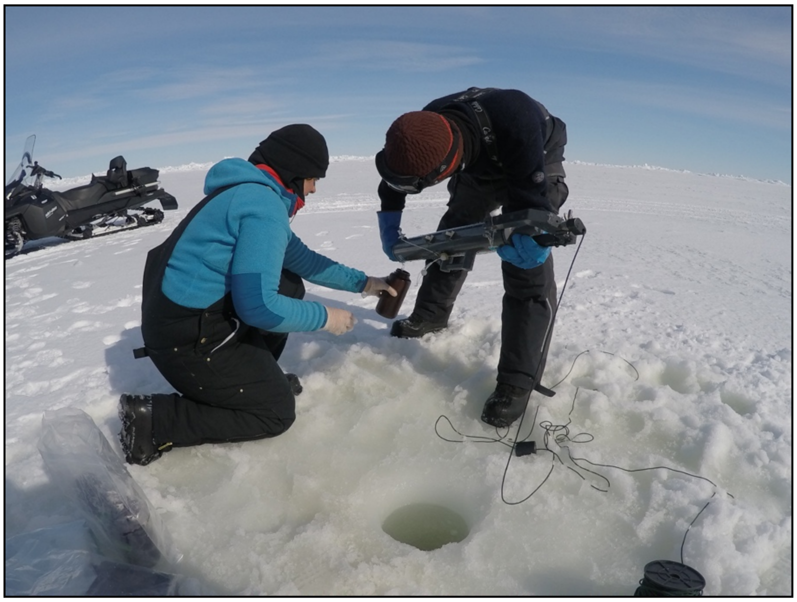


Figure 12 Water sampling using a niskin bottle

Reference

Holmes, R.M., Aminot, A., Kérouel, R., Hooker, B.A. and Peterson, B.J., 1999. A simple and precise method for measuring ammonium in marine and freshwater ecosystems. Canadian Journal of Fisheries and Aquatic Sciences, 56(10), pp.1801-1808.

Hansen HP, Koroleff F (2007) Determination of nutrients. In: Grasshoff K, Kremling K, Ehrhardt M, Weinheim W (eds) Methods of Seawater Analysis, New York.

Team 4 – Carbon System

Participants:
David Capelle Leg 01 – Feb 19 – Mar 11
Nicolas-Xavier Geilfus Mar 18 – Apr 05
Zakhar Kazmiruk Apr 5 – Apr 15

Note that the scientific lead of Team 4, Dr. Tim Papakyriakou did not come to Nanuk but was involved in all aspects of the science.

Team 4 Objectives and Activities

The main objective of Team 4 was to characterize the carbon system in major rivers, estuaries, landfast ice, and under-ice water over the late winter-early spring period, when carbon-system measurements are limited. Of particular interest was the influence of physical mixing of river water and marine water, as well as in-situ biogeochemical processes on the distributions of dissolved carbon, greenhouse gas (GHG) concentrations (including CO2 and CH4), and aragonite-saturation (Ωar), which is a proxy for ocean acidification.

Sample Collection

Water and ice samples were collected for dissolved inorganic carbon (DIC), total alkalinity (TA), dissolved organic carbon (DOC), methane (CH4), carbon-13-DIC (13C-DIC), salinity, and oxygen-18 (18O). Additionally, meteorological measurements were collected continuously to characterize air temperature, relative humidity, and wind velocity. In addition to the above measurements, we relied on data collected by other teams to interpret our results, including conductivity, temperature, and depth (CTD) data, ice temperature, and ice salinity, chromophoric dissolved organic matter (CDOM) and total suspended sediment (TSS). Samples were collected at the same locations as team 3 and team 5, including the Nelson and Hayes Rivers, an estuary site downstream from the Nelson River mouth, and along 3 cross-shelf transects spaced evenly along a ~50 km stretch of shoreline between the Hayes River and Cape Tatnum. Each transect was ~2 km long, and included between 2 and 3 stations, with a surface and bottom sample being collected at each site (only a surface sample was collected if water depth was less than 3 m beneath ice).

i) Water Samples
Water samples were collected either by submerging a Niskin bottle through a hole in the ice, or using a submersible pump. Samples for DIC and TA were collected in 250 mL or 500 mL glass

bottles with a scintered glass stopper. The bottle was overfilled 3x without introducing bubbles via a silicone tube, and sealed without a headspace in the field. In the lab, a headspace was added (1% of vial volume) to allow for thermal expansion, an d200 uL of saturated solution of $HgCl_2$ was added to preserve the sample, typically within 4 hours of sample collection. For all other water samples, a single 500mL glass bottle was overfilled 3 x without introducing air bubbles and sealed without a headspace in the field, and brought back to the lab for processing. Water was transferred from this bottle using a 50 mL glass syringe with a 10 cm long piece of 1/8" O.D. silicone tubing attached to the end. The syringe was rinsed 3x with sample water, then filled without introducing air bubbles, then dispensed into 2x 60mL glass serum bottles (CH_4), one 30 mL amber borosilicate glass bottle (13C-DIC), and 13 mL plastic centrifuge tubes (18O). Each bottle was carefully overfilled without introducing air bubbles and sealed without a headspace after preserving with 40 uL saturated $HgCl_2$ (CH_4), 20 uL saturated $HgCl_2$ (13C-DIC). No preservative was added to the 18O or salinity samples. For DOC samples, an acid-washed 60 mL plastic syringe was triple-rinsed with sample water, then an acro-disc filter was rinsed with 10mL sample water, before rinsing (3x) and filling a 20 mL glass scintillation vial, and adding 10uL pure Hydrochloric Acid (HCl). Vials were capped, wrapped with parafilm, and stored at 4degC until analysis.

ii) Ice Samples

Ice cores were collected using 9 cm diameter Kovacs core barrels, and sectioned into 5 cm or 10 cm sections, and vacuum sealed in plastic freezer bags, then melted overnight in the dark. Once melted, the bags were unsealed, and the glass syringe was again used to subsample for DIC, TA, CH_4, 13C-DIC, and 18O from each section. Due to smaller sample volumes, DIC and TA samples were collected in 5 x 12 mL glass vials, preserved with 10 uL saturated $HgCl_2$, and sealed with no headspace. 18O samples were collected in 2 mL glass vials with no preservative and no headspace. Salinity was measured in the remaining water using a hand-held probe, which was calibrated regularly.

iii) Meteorological Data

A meteorological station was installed near the Nanuk lodge at the start of Leg 1 to measure temperature, relative humidity, and wind-velocity. This included a 2-dimensional anemometer installed on a 4 m high tower, an air pressure sensor at x m height, and a radiation-shielding enclosure containing a thermometer and relative humidity sensor. Data was logged using a Campbell Scientific CR-1000 datalogger at 10-minute intervals, logging 10-minute averages, as well as min and max values, and standard deviations. The instruments and logger were powered by a 12-volt lead-acid battery. The met tower failed operated properly between Feb 20 – Mar 04 but failed thereafter and was not able to be repaired despite repeated attempts.

Data and Preliminary Results

Preliminary results show the rivers display elevated CH4 concentrations relative to marine waters, suggesting rivers supply CH4 to Hudson Bay. River were significantly super-saturated in CH4, while marine waters were only slightly supersaturated, suggesting the area would be a source of CH4 to the atmosphere once the ice cover melts away. Data from the campaign are available online (CanWIN) or by contacting David.Capelle@manitoba.ca.

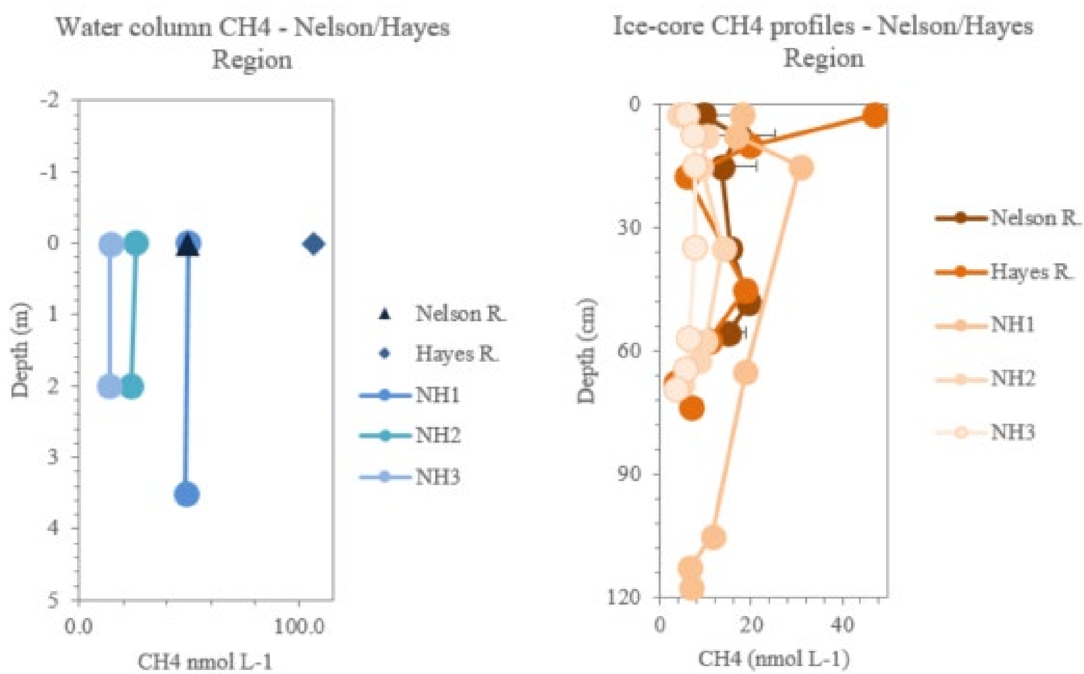


Figure 13 Example CH4 concentration from water and ice samples collected during Nanuk campaign

Team 5 – Contaminants

The objective for Team 5 was to determine total mercury (THg) and methylated mercury (MeHg) concentrations in water and ice across the gradient between the Nelson and Hayes Rivers and more saline waters of Hudson Bay. We also aimed to characterize the winter transport of THg and MeHg across the coastal shelf corridor.

The diversion of the Churchill River to augment the Burntwood-Nelson River System for hydroelectricity production increased the winter flow of Nelson River. Despite the higher volume, concentrations of THg and MeHg are lower in the Nelson River than in the Churchill

River (Kirk et al, 2008). In addition, THg in the Churchill River is primarily found in its dissolved form (Kirk et al, 2008), which may impact the persistence of THg from riverine sources and its potential for transformation to the biaccumulating chemical form MeHg in estuarine and marine waters of Hudson Bay.

The goal of constraining the wintertime estuarine sources and transport of THg and MeHg is to determine its importance relative to other potential sources into Hudson Bay, including marine waters, atmospheric, snowmelt, and how these are tempered by the seasonal sea ice boundary between the atmosphere and the marine water column.

Air Sampling

The Tekran 2537 atmospheric measurement system was set up in the rear portion of a staff cabin with the outside sampling components (1130 and 1131) installed outside the cabin facing northwest. The large power draw needed to run the particulate units prevented the collection of particulate mercury (Hg(II)) and reactive gaseous mercury species. As a result only gaseous elemental mercury concentrations were measured for the majority of the field campaign.

Water Sampling

Surface water from stations was collected by dipping bottles through the 8” auger hole in the ice wearing clean vinyl gloves.

Water column sampling was also accomplished by deploying a 2.5 L Niskin bottle from a metered line with a Teflon-coated messenger. All water sampling was accompanied by CTD deployment immediately prior to deployment of the Niskin bottle. The Niskin bottle deployment required a 10” auger hole through which the Niksin bottle in the cocked position and trigger mechanism were lowered down by hand. At the desired sampling depth, the Teflon coated messenger was released gently to minimize splashing of water. The line was then raised and the Niskin bottle was observed to determine whether the messenger successfully triggered the closure of the bottle. At times, we observed the freezing of water on the spring in the trigger mechanism. The freezing of the spring would result in a bottle misfire as the depressed trigger would block the top of the Niskin bottle from closing.

In order to prevent both the freezing of the spring as well as the spigot and valve, water was often sampled within the Eskimo brand ice-fishing tent using either a hair dryer or a Little Buddy brand car heater to thaw Niskin bottle components prior to deployment.

Samples were collected in 250 mL amber glass bottles. Bottles were rinsed with sample water prior to filling, filled to the shoulder, capped, and double bagged. Bagged samples were transferred to a filtered-air bubble constructed in a staff cabin at the Nanuk lodge in coolers with hot water bottles to prevent freezing. Care was taken to avoid cross contamination with sampling equipment and personnel involved in DIC/TA sampling and preservation, which requires use of high concentrations of HgCl2 as a preservative agent.

Ice Sampling

Ice cores were collected using the 9 cm Mark II Kovacs core barrel in conjunction with teams 1, 3, and 4 from 2 landfast ice. Cores were bagged in core bags, labeled in the field, and transferred to the lodge. Cores were cut with a metal Japanese saw into 5 cm portions outside of the main building (ambient temperature < -20 °C) in order to prevent thawing. All edges of each core section were then trimmed with ceramic knives to remove ice that came into contact with the core barrel or the metal saw. Trimmed sections were double bagged in new Ziploc bags and kept at room temperature in order to melt.

After melting indoors in Ziploc bags, the ice core sections were processed identically to water samples.

Sample Processing

Ideally, the processing of trace metal samples is carried out in clean room environments under HEPA-filtered, or equivalent, air supply. Because no certified clean room was available at the lodge, a small filtered air bubble was created using plastic sheeting around a Mac10 HEPA filter unit.

A bubble was constructed to minimize falling dust or particles into open bottles during filtration and preservation. All sample filtration and preservation equipment was kept within the bubble throughout the duration of the field program.

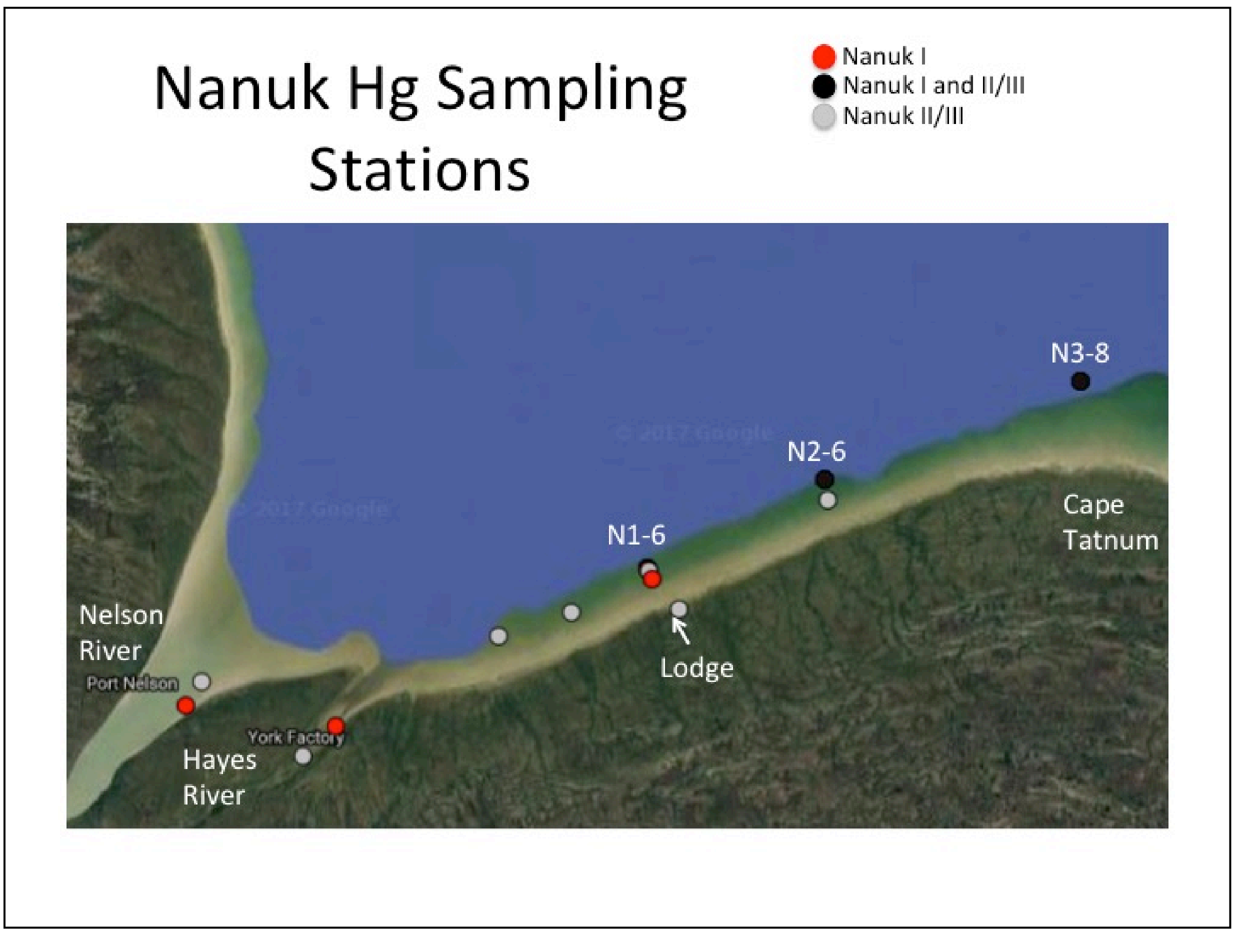
Double-bagged samples were removed from coolers. Outer bags were removed and samples in inner bags were transferred to the lab bench tent and opened to remove sample bottles. Either a separate 250 mL bottle or ~125 mL of a sample were filtered through Thermo Scientific Nalgene disposable analytical filtration (0.45 μm, 47 mm) units using a Nalgene hand pump under 5 – 10 psi pressure. Filtration unit and filtrate collection bottles were rinsed 3x prior to filtrate collection. Filter cups were kept covered as much as possible during filtration.

Filters were removed, stored in PetriSlides (EMD Millipore) marked with filtered volume, and stored at -20 °C.

Unfiltered and filtered water and ice samples were preserved to 0.5% HCl (concentrated HCl, JT Baker) and stored in coolers in the dark until transfer to the University of Manitoba for future analysis.

Incubation Experiments

Known amounts of isotope enriched mercury species (MM198Hg and 202Hg(II)) were added to water and ice samples for known incubation times to measure potential rates of in situ mercury methylation and demethylation. Following incubation periods, and melting of ice core sections, samples were preserved as for water samples and transported for analysis.



References

Kirk JL, St. Louis VL, Hintelmann H, Lehnherr I, Else B, Poissant L (2008) Methylated mercury species in marine waters of the Candian High and Sub Arctic. Enivron. Sci. Technol. 42:8367-8373.

Appendix A: Sampling Schedule

Date	Transect	Station	Hg-Water Sampling	Hg-Ice Sampling	Hg-Air Sampling	Notes
23-Feb-17	Lodge transect					Established sites prior to arrival of sampling gear
24-Feb-17						Gear arrived, set up clean lab
25-Feb-17	Cape Tatnum transect	N3-8	1m, 3m, 5m, 7m			
26-Feb-17	Middle transect					
27-Feb-17	Hayes and Nelson Rivers	Hayes River	Surface water			
28-Feb-17	Lodge transect	N1-5	1m, 2.5m			
		N1-2	Surface water			
01-Mar-17	Hayes River					No water sampled, auger hit ground
02-Mar-17					Air system maintenance	
03-Mar-17	Nelson River	Nelson River	Surface water			
04-Mar-17	Packing					
05-Mar-17	Blizzard delay					
06-Mar-17	Blizzard delay					
07-Mar-17	Blizzard delay					

08-Mar-17	Blizzard delay				Air system covered in snow	
09-Mar-17	Blizzard delay					
10-Mar-17	Blizzard delay				Air system restarted	
11-Mar-17	Departure					
18-Mar-17	Arrival				Air system maintenance	
19-Mar-17	Lodge transect				Air system restarted	
20-Mar-17	Snow				Air system tripped, restarted	
21-Mar-17	Lodge transect	N1-6	1m, 3m			Set up microplastic experiment with Nix
22-Mar-17	Nelson River	Nelson River	Surface water	Core collection		
23-Mar-17	Hayes River	Hayes River	Surface water	Core collection		
24-Mar-17	Lodge transect					
25-Mar-17	Middle transect	N2-6	1m, 2.5m, 5m			
	Opoyastin River	Opoyastin River	Surface water			
26-Mar-17	Cape Tatnum					Turned back from Cape Tatnum due to snow
27-Mar-17	Cape Tatnum					Escorted others to Cape Tatnum, no light for sampling

28-Mar-17	Lodge transect					Microplastic sampling
29-Mar-17	Crew change/lodge transect					
30-Mar-17	Cape Tatnum transect	N3-8	1m, 3.5m, 7m			
31-Mar-17						
01-Apr-17	Cape Tatnum	N3-8		Core collection for incubation		
02-Apr-17	Snow					
03-Apr-17	Snow					
04-Apr-17	Snow					
05-Apr-17	Middle transect	N2-6	1m, 2m water	Core collection		
06-Apr-17	Lodge transect	N1-6	1m, 2m water, 1m incubation water			
07-Apr-17	Lodge transect	N1-4	1m water, incubation water			
	Menahook River	Menahook River	1m, 3m			
	Fourteens River	Fourteens River	55cm, 2m			

08-Apr-17	Middle transect	N2-6	55cm, 6m, 55cm incubation water			
	Middle transect	N2-3	1m, 3m, 1m incubation water			
09-Apr-17						
10-Apr-17					Air system taken down, packed	
11-Apr-17	Lodge transect	N1-6	1m, 3m water, 1m incubation water			
		N1-4	1m, 2m water, 1m incubation water			
12-Apr-17	Lodge transect					Microplastic sampling
13-Apr-17	Packing					
14-Apr-17	Packing					
15-Apr-17	Departure					